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How do climate change and associated hazards impact on the resilience of riparian rural communities in Bangladesh? Policy implications for livelihood development

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ABSTRACT

Despite the increasing recognition of the need for building resilience among poor farmers in developing countries in the face of changing climate conditions, there is a lack of information on the various factors influencing their resilience capacity. This paper develops an indicator-based Resilience Capacity Index (RCI) aimed at a better understanding of the factors influencing resilience capacity of the most hazard-prone riparian rural households in Bangladesh, as a case study in a developing country. The RCI is a relative measure and the value ranges between 0 and 1, where the higher the value the higher the resilience capacity. The index value of 0.297 for riverine mainland households is significantly higher than that for *char* (island) households (0.201). However, the lower index values in both locations infers the households' inability to cope with and adapt to the impacts of climate change and associated hazards due to a lack of adaptation options along with their poor socio-economic conditions. The main drivers of the resilience capacity include livelihood strategies, level of education, and access to food, water and health services. Creating employment opportunities, increasing the level of education, and ensuring access to food, water and health services are potential climate-resilient strategies that are likely to enhance the resilience capacity of most vulnerable riparian households across Bangladesh, with some experiences which may be replicable elsewhere.

1. Introduction

Climate change is a matter of prime concern to Bangladesh. Due to its low-lying deltaic geographical position, the country is regarded as being among the nation's most vulnerable to climate change (IPCC, 2014, 2007; WB, 2013; GoB, 2010). However, the impact of climate change varies spatially and over time meaning that all communities are not vulnerable equally (Gentle et al., 2014; Fussel, 2007). To minimize negative livelihood impacts, differential and more targeted livelihood options and resources for adaptation need to be considered (Alam, 2016; Gentle et al., 2014; IPCC, 2014).

Coastal and riverine households in Bangladesh are the most susceptible to the impact of climate-driven hazards, including riverbank erosion (Alam, 2016; GoB, 2010). Recent models of the hydrological impact of climate change in different climatic zones have shown this to be true across Asia (Eregno et al., 2013). Moreover, Bangladesh has a monsoonal climate that creates frequent and heavy rainfall resulting in a higher frequency of catastrophic floods in the country (Huq et al., 1996). Increased monsoonal flows result in greater sediment transport capacity and so the morphologic dynamics of the rivers leads to increased riverbank erosion along the Ganges–Brahmaputra–Meghna delta (Alam, 2016; Gain et al., 2013; Huq et al., 1996).

Riverbank erosion, a factor which accounts for the largest losses in Bangladesh, occurs gradually but has long-term impacts and is not recoverable naturally (Alam, 2017; Penning-Rowsell et al., 2013). Approximately 8700 ha of homestead and farming land are lost due to riverbank erosion each year, which displaces approximately 200 000 people annually and contributes to an increase in their vulnerability in terms of food security and poverty (IFAD, 2013; Penning-Rowsell et al., 2013; GoB, 2010). Due to the dynamics of erosion and accretion in the

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rivers of Bangladesh, some land emerges as *chars*[1] (sandbars/sand and silt landmasses) within the river channel or attached land to the riverbanks. Households in *char* areas are marginalized from the benefits of mainland people due to poor infrastructure and communication networks (Alam et al., 2017a,b; Alam, 2016; Sarker et al., 2003). Resource-poor households in the riverine areas are more exposed to the impact of frequent floods and waterlogging because of their proximity to the rivers, which also increases their vulnerability. Moreover, due to climate change, the households are also expected to experience projected increases in mean annual temperatures, uncertainty in rainfall, a likely reduction of cereal crop productivity, and surges in disease, pest and weed pressure on their crops and livestock (Alam, 2016; Niang et al., 2014).

In such unavoidable circumstances, there is an increasing recognition by many government and non-government agencies globally of the need for resilient practices and for building the resilience capacity of the poor and small landholder farmers in order to cope with increasing climatic hazards (IPCC, 2014; UN, 2013; WB, 2009). Increasing resilience generally reduces vulnerability (Folke, 2006). A lack of resilience may lead to migration, as seen in Bangladesh and India (e.g., Alam et al., 2017a,b; Jha et al., 2017). Rural households have always faced extreme and unexpected events, but their ability to respond effectively to the increasing incidence of shocks needs to be strengthened (de Bruijn et al., 2017; Alam, 2016). Scholars have argued that resilient households are more likely to anticipate, resist, cope with and recover from shocks (Barua et al., 2014; Fan et al., 2014). However, there has been a lack of information about the factors influencing such household resilience, particularly the socio-economic resilience of disaster-prone households (Qasim et al., 2016; Speranza et al., 2014; Akter and Mallick, 2013; Cutter et al., 2008). Despite much attention to the notion, policy makers and practitioners are not yet clear how resilience thinking can translate into practical implementation strategies while they refer to resilience as something to pursue for facilitating long-term adaptation practices in particular (de Bruijn et al., 2017; Dhar and Khirfan, 2017; Crowe et al., 2016; Tambo, 2016).

The livelihoods of resource-poor rural households in developing countries like Bangladesh are generally dependent on natural resources and the capacity of the households to cope with and adapt to the compounding influences of climate change and its associated hazards is largely uncertain due to the poor socio-economic condition of the households (WB, 2013; IPCC, 2007). A loss of resilience of a natural resource-dependent household contributes to an increase in its vulnerability to shocks which could have been absorbed previously (Kasperson and Kasperson, 2001). One of the principal objectives of disaster risk mitigation strategies is to achieve disaster-resilient communities (IPCC, 2007). Policy makers are interested in knowing what affected people can do for themselves and how to best support the capacity of resource users to cope with and adapt to climate change and its associated hazards (Kulig et al., 2013; Nelson et al., 2007; Walker et al., 2004).

Given the severe climate-related hazards, the Bangladesh Government has given a high priority to improving the livelihoods of rural people, particularly the marginalised riparian households (GoB, 2016). Therefore, it is crucial that household resilience strategies resulting from their long-term knowledge, experience and practices are understood better so that policy makers will be enabled to ensure policies are targeted to appropriate climate adaptation processes to mitigate the effects of an adverse climate and associated hazards in the country (Alam, 2016; Preston et al., 2011; Marshall, 2010; Tompkins and Adger, 2004). Although the resilience concept is applied in diverse field with varied definitions, in this study resilience is defined as the ability of households or communities to effectively cope with and adapt to the riverbank erosions and other climatic hazards in such a way that helps to minimalize the loss of life and economic assets.

Despite the increasing focus on the resilience concept, limited attention has been paid to the resilience measurement aspect. Therefore, the focus of this study is on assessing the resilience of vulnerable riverine households from socio-economic perspectives by developing an indicator-based Resilience Capacity Index (RCI). The assessment method will enable policy makers to know where policies need to be directed to build livelihood resilience, to reduce the vulnerability of individual households and the community, and to monitor the effectiveness of the policies and practices targeted to build resilience. There are two research questions to be answered:

i What factors influence the resilience capacity of riverine mainland households and *char* households in Bangladesh?; and
ii Are the riverine mainland households in Bangladesh more resilient than the *char* households to riverbank erosion and other climate change issues?

The rest of the paper is organized as follows: section two describes the methodology for assessing the resilience capacity followed by the description of the study area and the data collection procedure. The paper then shifts to the survey results followed by a discussion in section three. Section four provides the policy implications and section five concludes the study.

2. Methodology

2.1. Study area and sampling

About 20 out of the 64 districts in Bangladesh are prone to riverbank erosion that causes displacement of people along the estimated 150 000 km of riverbanks annually (GEGIS, 2012; GoB, 2010). Therefore, two riverbank erosion affected districts, two Upazila[2] and villages were selected based on the degree of severity of erosion that was identified through a review of the literature, reports in newspapers and consultations with local experts. Respondents were selected randomly from each village. For the field survey, the Chauhali Upazila of the Sirajgonj district and the Nagarpur Upazila of the Tangail district were selected (Fig. 1), as they were representative of severe riverbank erosion-affected riparian environments in Bangladesh. The area is about 200 km north of Dhaka, the capital of Bangladesh. The study area contains the Jamuna[3] riverbank erosion zone where about 2000 ha are eroded each year (GEGIS, 2012). In the coming decades the households are expected to face even more flooding, increasing drought conditions and water supply pressures, higher temperatures, sea level rise and more intense storms (Alam, 2016; WB, 2010).

The study households were divided into two groups based on their location, namely; riverine mainland households and *char* households. Although both groups of households are affected by riverbank erosion and other climatic hazards, their different locations with respect to the river means the impact on livelihood vulnerability is different for each and they adopt different response strategies. Households in the *char* area are isolated from the mainland by the river and are deprived of all standard government services, whereas the riverine mainland households are relatively better off through being better connected to transport and other services. The *char* villages included were Moradpur, Datpur and Kairat, and the mainland villages were Atapara, Kash Pukuria and Kash Kawalia.

[1] According to the estimates of EGIS (2000), the *char* area covers about 5% of the total land area of the country and it contains about 6.5 million people (5% of the total population of about 156.6 million in 2014; BBS, 2014).

[2] Lower administrative unit of government; below district level but above village level.

[3] Bangladesh is composed of the floodplains and delta of three main rivers – the Padma (Ganges in India), the Jamuna and the Meghna (Brahmaputra in India). There are more than 230 rivers in the country. These three rivers and their tributaries are prone to continuous erosion and are one of the most significant hazards in Bangladesh.

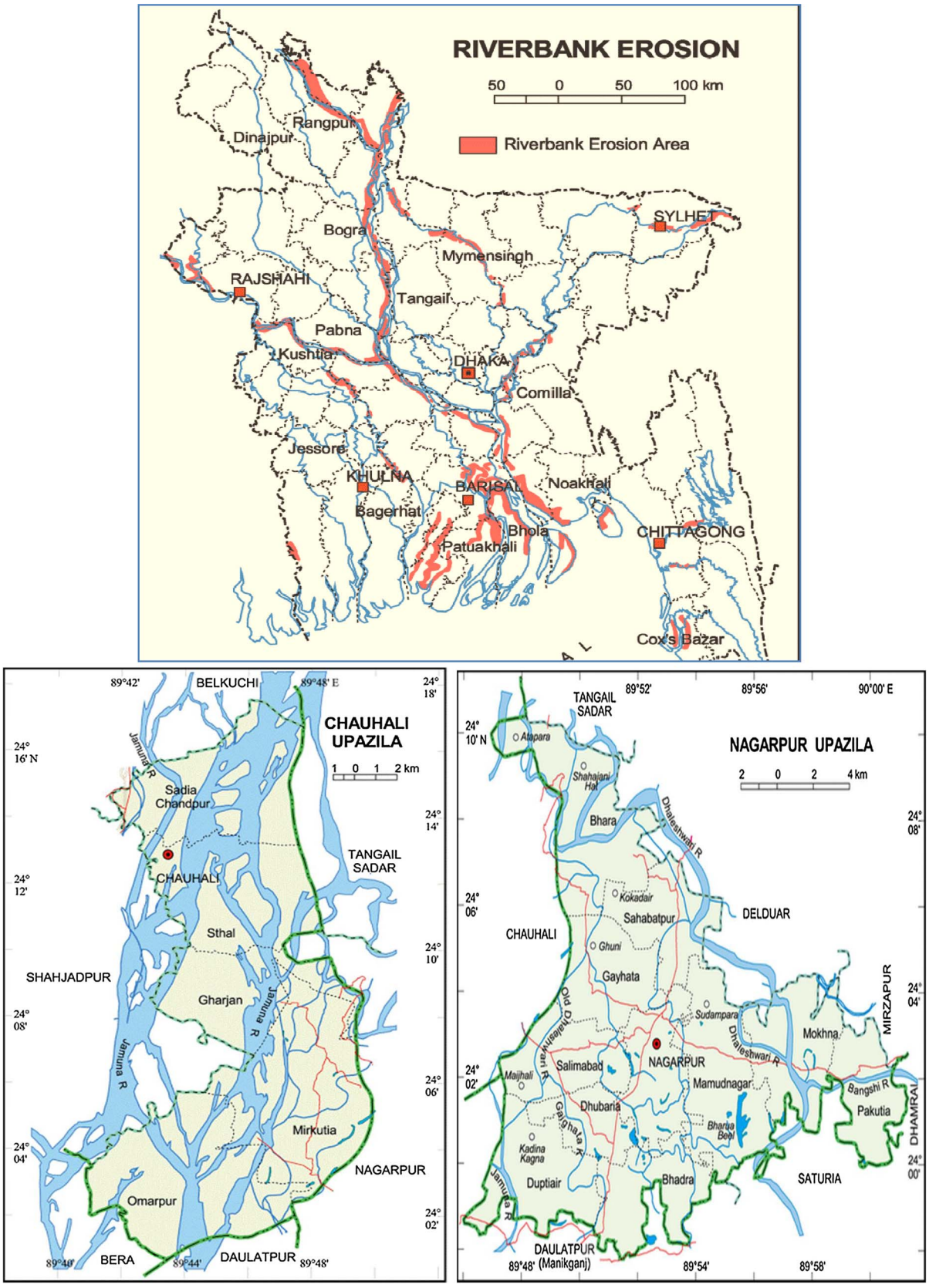

Fig. 1. The study area: the Nagarpur and Chauhali Upazilas.

2.2. Data collection

The unit of analysis was the rural household and for data collection the household head (either male or female) was the survey participant due to their decision-making authority over production, consumption and resources within the household. From each village, 15% of the household heads were interviewed giving a sample size of 380 households for the study.[4] To ensure randomness in sampling, a computer-generated random number table was applied to the list to select these households. In the case of non-response, the interviewers simply proceeded to the next household until the required number of respondents for a particular village was reached.[5] Moreover, one focus group discussion was conducted in each village with 10–12 household heads to obtain their views on various climatic and socio-economic variables. These opinions were then used to cross-validate the information obtained from the surveys and the key informant interviews.

The study developed a structured survey questionnaire[6] to collect data using face-to-face interviews between January and May 2015. Prior to the survey, the questionnaire was tested with 20 respondents to ensure the adequacy of the information obtained and to avoid ambiguity in the questions. The questionnaire sought information on socio-demographic conditions, perception of climate change issues and response strategies. The principal author along with three trained enumerators implemented the survey. Some non-parametric tests such as a simple *t*-test were performed to assess the difference in the resilience capacity of the two study groups.

2.3. Developing the resilience index

The theoretical construct of resilience is an evolving concept which is often described as a positive adaptive response[7] to adversity (Maru et al., 2014; Wilson, 2012). In the face of unanticipated climate-driven shocks and stresses, building resilience is a worthy strategy to adopt where vulnerability may not be apparent in advance (de Bruijn et al., 2017; Tyler et al., 2016). There are important aims in employing resilience theory in empirical studies; it can be used to assess the current state of the socio-ecological system, make predictions about whether or not the system is resilient and determine how the impact of climate change will be experienced (Stokols et al., 2013; Cumming et al., 2005). Scholars and researchers have described resilience as a mechanism of change, self-organization, the capacity to learn from experience, or to process information and adapt accordingly (Goldstein et al., 2015; Carpenter et al., 2012; UNDP, 2011; Cutter et al., 2008; Marshall and Marshall, 2007; Gallopin, 2006; Folke, 2006; Adger et al., 2005; Berkes and Seixas, 2005; Cumming et al., 2005; Walker et al., 2004; Klein et al., 2003). The multiple meanings of resilience acknowledge the presence of either single or multiple equilibria in a socio-ecological system (Holling, 1996). However, Davoudi (2012) argued that resilience in a socio-ecological system does not necessarily have one or more equilibrium states, but is adapting and changing continuously as compared with engineering systems.

Vulnerability, on the other hand, is often denoted as the antonym, i.e., the flip side, of resilience (Folke et al., 2002). Researchers have referred to vulnerability as a combination of sensitivity, exposure and adaptive capacity (Paavola, 2008; IPCC, 2007). Resilience, unlike vulnerability, does not include exposure to a disturbance (Tyler et al., 2016; Gallopin, 2006). Nelson et al. (2007) argued that vulnerability and resilience are considered to be linked to one another via response capacity. These two terms are used synonymously (see, e.g, Adger, 2006; Smit and Wandel, 2006). However, some viewed vulnerability and resilience as two distinct concepts with some components in common (Sapountzaki, 2012; Cutter et al., 2008). Some scholars have treated resilience as an isolated concept in their disaster analysis. They have focused on some specific strategies such as microfinance and migration for communities, households or individuals to rebound after disaster (Mallick and Vogt, 2012; Mohapatra et al., 2012; Parvin and Shaw, 2012). Some researchers have considered resilience as integral to sustainability (Berkes and Ross, 2016; Magis, 2010). Perez et al. (2015) considered fostering resilience as the equivalent of building the ongoing adaptive capacity of individuals and social organizations.

Given the lack of a widely accepted framework of resilience assessment, this study adopted the concept of resilience proposed by Malone and Brenkert (2008), Brenkert and Malone (2005) and Moss et al. (2001). They have referred to resilience as a function of sensitivity and adaptive capacity as follows:

$$\text{Resilience} = f(\text{Sensitivity},\ \text{adaptive capacity}) \quad \text{(i)}$$

Sensitivity (the potentially negative impact of climate change) and adaptive capacity (the capability to maintain the status quo, minimize losses or maximize gains) are, in turn, composed of different elements that have various indicators. In the sensitivity dimension, the elements are health, food and water (Aryal et al., 2014; Shah et al., 2013; Hahn et al., 2009). The adaptive capacity consists of the household's socio-demographic profile, livelihood strategies and social networks (Pandey and Jha, 2012; Hahn et al., 2009; IPCC, 2007).

The selection of indicators depends mostly on an intensive review of the literature on the one hand or relies heavily on field experience on the other. We have combined both approaches, especially incorporating the field experience, and we followed this procedure to select the 30 indicators for this study (Appendix A). Resilience can be studied at different levels – individual, household, group, village, nation or system. Rural households have always faced extreme and unexpected events, but their ability to respond effectively to the increasing incidence of shocks needs to be strengthened. We considered the capacity of riverine rural households to absorb unpredictable shocks and stresses. We consider both short term actions that help households to cope in the case of shock and long-term actions that contribute to building resilience over time. However, it can be argued that the indicators are not representative enough to assess resilience. This issue is not uncommon in any indicator set (see, e.g., the Wellbeing Index (Prescott-Allen, 2001) and the Livelihood Vulnerability Index (Shah et al., 2013; Hahn et al., 2009). Moreover, each indicator was developed in the context of a specific research aspect and geographical region. The choice of indicators and their weighting are always subjective arguments (Huang et al., 2012; Eriksen and Kelly, 2007). In developing the RCI this research focused on quantifying the strength of current livelihoods and food, health and water resource characteristics as well as the capacity of households and communities to alter these strategies in response to climate-related events.

The next issue is allocating a score to each indicator. In this study we assigned a score to each contributing indicator rather than to any of the dimensions as a whole. This score is based on the knowledge of the local experts and scholars with an emphasis on the inductive approach[8] (Qasim et al., 2016; Islam et al., 2014). The researchers first provided a score based on the literature review. These scores were then amended and/or agreed upon by the local experts and the participants in the focus group discussions.

There is, unsurprisingly, mixed opinion in making an index without weighting the variables. Some scholars have argued that the use of

[4] For the cross-sectional household survey, 5% of the population is considered adequate (Bartlett et al., 2001).

[5] The unavailability of the respondent or a refusal to answer questions were mainly in the female-headed households, which cover less than 2% of the actual samples.

[6] The questionnaire can be found at www.usq.edu.au/library.

[7] Although any response may increase resilience in the short term, it can create great vulnerability in the long term (Maru et al., 2014).

[8] For analysing qualitative data this approach provides an easily used and systematic set of procedures likely to be guided by the researcher that can produce reliable and valid findings. See Thomas (2006) and Goddard and Melville (2004) for further details.

weights and the weighting method depend on the local factors and circumstances where the method is applied (Alam, 2016; Alam, 2017; Crowe et al., 2016; Reisi et al., 2014). Eakin and Bojorquez-Tapia (2008) noted that equal weighting makes an implicit judgment about the degree of influence of each indicator and they proposed a logic-based weighting method as a more objective approach. Vincent (2007) and Sullivan et al. (2002) suggested using expert opinions and stakeholder discussions to determine weighting schemes. Other scholars, however, have argued that an average of the various variables can be used directly for indexing. For example, Kaly et al. (2005, p.5) argued that 'simple averages across indicators were used because they can be easily understood, and more complex models do not appear to offer any advantages to expression or utility of the index'. Some researchers (see, e.g., Vincent, 2007 and Briguglio, 1995) argued that weighting schemes would not solve the problem of a subjective choice of variables. Moreover, there is no evidence of the higher validity of weighted variables compared with non-weighted variables (Angeon and Bates, 2015). Many indexes use a non-weighted average to integrate their components. For example, the Composite Vulnerability Index of the Center for Environment and Development 2002 (Kaly et al., 2005; Turvey, 2007) and the Economic Vulnerability Index-EVI of the UN Committee for Development Policy (UN, 2008). It is also argued that non-weighted variables would not change the message conveyed through an index in comparison with weighted variables (Tambo, 2016; Angeon and Bates, 2015). Most of the vulnerability indices are non-weighted averages of indicators and weighted average of components (Alam et al., 2017a,b; Aryal et al., 2014; Shah et al., 2013; Pandey and Jha, 2012; Hahn et al., 2009; Turvey, 2007). Therefore, in this study, instead of emphasizing relative weights of different variables, we gave greater consideration on multiple variables to assess resilience in a complexity setting (e.g. rural residents in *char* land). Thus, in line with the existing literature, an equal weighting for all indicators included in the model is applied.

The measurement of resilience is a relatively new issue in a developing country context. However, there is no agreement on how best to measure it. In this study simple arithmetic functions were used to calculate the scores for indicators and the dimension of resilience capacity (Tambo, 2016; Angeon and Bates, 2015; Mazumder and Lu, 2015; Habiba et al., 2011; Turvey, 2007). In RCI each component/dimension contributes differently to the overall index, since each component is comprised of a different number of indicators.

First, the index value of each indicator was calculated using the equation as follows:

$$Index_{In_a} = \frac{\sum SIn_{ai}}{n} \quad \text{(ii)}$$

Where In_a is one of the indicators for an area a, $SIna_i$ represents the total score of each indicator, indexed by i, and n indicates the number of observations. After getting an index value of indicators, the next step was to estimate the index value of each component which was calculated using the equation as follows:

$$C_a = \frac{\sum index_{In_{C_i}}}{\sum S_{C_i}} \quad \text{(iii)}$$

Where C_a is the index value of one of the components for an area a, $index_{In_{C_i}}$ represents the value of indicators in each component, indexed by i, and S_{C_i} indicates the value of indicators in each component.

Once the index value of each component was calculated, they were then used to calculate the index value of sensitivity and adaptive capacity. The index value of sensitivity (Sen) was calculated as follows:

$$Sen = \frac{W_{sen1}Health_{+}W_{sen2}Food + W_{sen3}Water}{W_{sen1} + W_{sen2} + W_{sen3}} \quad \text{(iv)}$$

Where W_{sen1}, W_{sen2} *and* W_{sen3} are the weight for the components health, food and water, respectively.

The index value of adaptive capacity (AdaptCap) was calculated as follows:

$$AdaptCapty = \frac{W_{ad1}SD + W_{ad2}LS + W_{ad3}SN}{W_{ad1} + W_{ad2} + W_{ad3}} \quad \text{(v)}$$

Where W_{ad1}, W_{ad2} *and* W_{ad3} represent the weight for the components of socio-demographic conditions, livelihood strategies and social networks, respectively. Each dimension will attain a maximum value of 1 and a minimum value of 0.

Then the index value for sensitivity and adaptive capacity are combined to calculate the RCI as follows:

$$RCI = \{Senvity - Adap.\ capty\} \quad \text{(vi)}$$

The higher the value of the RCI, the higher the resilience capacity and vice versa. Some caution needed to be taken in interpreting the results, since the results are expressed in relative terms, rather than absolute, and are assessed at the scale of 1 (most resilient) to 0 (least resilient).

3. Results and discussion

In this section, the results are described and discussed in different stages.

3.1. Socio-demographic conditions

The details of the socio-demographic information are summarised below. These can provide critical information for potential policy interventions to improve the livelihoods of the vulnerable households:

- The study revealed that 33% of households had lost their homestead more than three times and 57% at least once during the past 10 years.
- The average land holding of the households was 0.56 acres (small farms are common in Bangladesh). About 32% of the households were landless.
- About 29% of the households had no education, and the average years of schooling were below primary level (3.17 years). In addition, 17% of the households did not send their children to school due to a lack of education facilities. The distance to the nearest school was more than 2 km and the road network was fragile and inadequate. Inadequate road and transport facilities also serve as substantial barriers for households to participate in the non-farm activities. The average family size of 5.21 is relatively large compared with the national average of 5.0 (BBS, 2014).
- Regarding hygiene issues, more than 19% of the households did not have any sanitary toilet facilities and 47% had no safe drinking water facilities and many of them had tube-well facilities with arsenic contamination. The average distance to a safe drinking source was more than 1 km. These issues mainly affect the households which had lost their homestead.
- The households were also found to be deprived of many standard government services. About 56% of the households were without electricity, and the availability of health facilities was also limited. Riverbank erosion destroyed the only public hospital in the Chauhali Upazila in 2014 after which many residents had to travel a longer distance (more than 2.5 km) to reach the nearest health and veterinary centres.
- Moreover, the existence of governmental or formal financial institutions, including non-government organizations (NGOs), in the area was inadequate. About 59% of the households had no contact with the extension service providers from whom they can obtain advice related to agriculture and rural development. They also had less farmer-to-farmer contact (64%) and less involvement with different organisations, including membership of cooperative societies (35%), from whom they can receive information and assistance.

Table 1
The indexed value of the components and indicators comprising the resilience capacity index.

Components	Index value of each component		Indicators	Indexed value for each indicator	
	Char households	Riverine mainland households		*Char* households	Riverine mainland households
Socio-demographic profile	0.397	0.503	Dependency ratio?	0.168	0.373[a,**]
			Education level?	0.894	1.242[b,***]
			Do you adopt any contraceptive method?	0.905	0.941
			Does your family send children to school?	0.873	1.000[a,*]
Health issues	0.494	0.823	Does your family use a sanitary toilet?	0.913	0.987
			Do you have a family member with a chronic illness?	0.863	0.943[a,*]
			Access to health facilities?	0.000	0.778[a,***]
			Current health condition of the household head?	0.692	1.407[b,**]
Water	0.775	0.938	Does your family use tube-well water?	0.963	1.000[a,*]
			Distance to the source of safe drinking water?	0.586	0.876[a,**]
Food	0.230	0.515	Household food secure or not?	0.412	0.688[a,**]
			Do you adopt zero-tillage cultivation?	0.681	0.795[a,**]
			Do you adopt new cropping practice?	0.342	0.89[a,***]
			Do you adopt improved management of weeds and manure?	0.114	0.769[a,**]
			Do you adopt IPM?	0.045	0.623[a,**]
			Do you cultivate multiple crops?	0.051	0.813[a,**]
			How many months can you provide food from your family farm?	2.12	4.513[b,***]
			Do you practice homestead gardening?	0.712	0.471[a,*]
			Do any member of your family included in social safety net programs?	0.123	0.743[a,**]
Livelihood strategies	0.379	0.430	What is your main profession?	1.178	1.663[b,*]
			Do you receive remittance from a family member who has migrated to the city?	0.167	0.375[a,**]
			Do you practice tree plantation?	0.457	0.492
			Do you allow your family women members to work outside home?	0.854	0.482[a,*]
Social network	0.111	0.446	Are you a member of any cooperative society?	0.078	0.421[a,***]
			Have you any savings account?	0.014	0.753[a,**]
			Have you received any training in your profession?	0.047	0.218[a,**]
			Do you explore and utilize information technology for professional, health and family planning activities?	0.034	0.337[a,***]
			Are your family members a member of a cooperative society?	0.213	0.436[a,**]
			Do you allow women in the decision-making process?	0.114	0.342[a,**]
			Do you get cooperation from other village people in case of your need?	0.274	0.612[a,*]
Overall resilience capacity index				**0.204**	**0.299**[**]

* $p < 0.10$.
** $p < 0.05$.
*** $p < 0.001$.
[a] Fisher's exact test.
[b] T-statistics for mean difference test.

3.2. Resilience index

The overall RCI of 0.299 for the riverine mainland households was found to be significantly higher compared with the *char* households (0.204) ($p < 0.04$) (Table 1). This indicates that riverine mainland households were relatively more resilient than *char* households. The results reject the null hypothesis that there is no difference in RCI between the two groups. However, both of them had a low index value that indicated a truncated capacity for the households to be resilience to climate change and associated hazards.

The results also showed quite a large difference in the estimated index values for the components of health, food, water and social networks between the study sites. The index values for health, food, water and social network were higher for the riverine mainland households – 0.823, 0.515, 0.938 and 0.446, respectively compared with 0.494, 0.230, 0.775 and 0.111 for the *char* households, respectively (Table 1). The highest index values demonstrated the relative higher resilience capacity of riverine mainland households in those areas than the *char* households (Fig. 2). The index value for the components of socio-demographic conditions and livelihood strategies varied slightly across the sites.

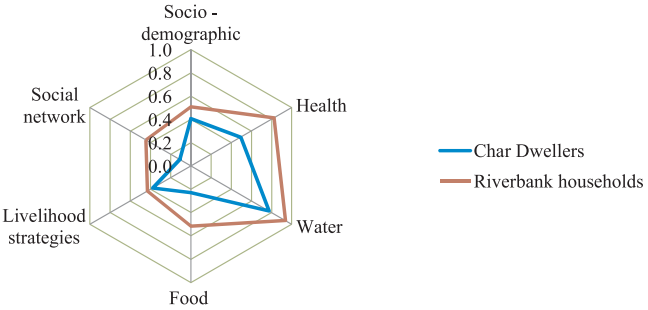

Fig. 2. Indexed value of the components.

A considerable variation was observed between indicators. For instance, the level of education (0.894, as against 1.242), access to health facilities (0, as against 0.778), the adoption of new agricultural practices (0.261 as against 0.764), the ability to supply food from own production (2.12, as against 4.513), access to familial and kinship networks (0.188, as against 0.499) were low for the *char* households compared with the riverine mainland households which contributed to

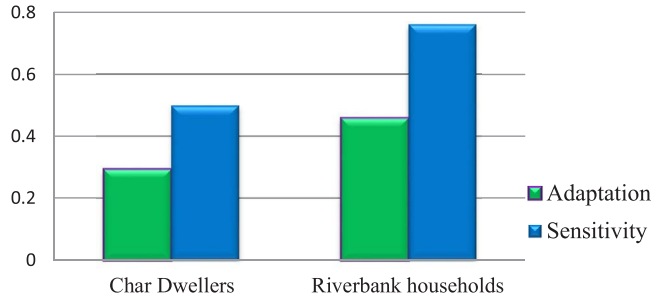

Fig. 3. Index dimension of resilience.

limiting the resilience capacity of the *char* households (Table 1). The index value for the dimensions of sensitivity and adaptation were significantly higher for the riverine mainland households than for the *char* households at 0.499 and 0.759, and 0.296 and 0.460 respectively (Fig. 3).

4. Discussion

The variation in the RCI indicates that the resilience capacity of hazard-prone households varies across locations, at both an overall level and, more dramatically, in relation to the particular components and indicators.

4.1. Health component

Access to health facilities is one of the important limiting factors for the resilience capacity of the *char* households. This can be explained by the reason that they have to travel a longer distance (more than 2.5 km) to reach health and veterinary centers (Table 1). The *char* area is isolated from the facilities of the riverine mainland area and a boat is the main form of transport which naturally takes more time. Besides, many of those households still believe in their traditional systems to recover from sickness rather than visiting local doctors. Their low-income profile and the unavailability of health services are also responsible for their belief. Low income means cutting back their minimum consumption requirements to pay for health care services. The number of chronically ill people is higher in the *char* areas (Table 1). Moreover, most of them are in a poor category of health which reduces their wage-earning ability and thus increases their vulnerability to food insecurity. They are deprived of all kinds of standard government services. They have limited human resources in terms of formal education (below primary level) and skills which limit their options when seeking employment opportunities in the non-farming sectors. Human capital development is an important pathway to enhancing the resilience capacity of the vulnerable households (Alam et al., 2016; Magis, 2010). The confluence of a low level of education and awareness coupled with their traditional belief in recovery from sickness makes *char* households more vulnerable and reduces their resilience capacity.

4.2. Education

There is a lack of primary education facilities in the *char* household area. Children in that area need to go to the mainland to access education facilities. The distance involved is more than 2 km and the road network is fragile and inadequate. The confluence of the distance and time to the education facilities and the family need for extra income conspire to have many households engage their children in some income-earning activities instead of sending them to school which ultimately reduces their future income-earning opportunities in the formal job sector.

4.3. Water component

Many of the *char* households were found to use unsafe drinking water, mainly from the river although most of the several tube-wells available to them were reported to be contaminated by arsenic. The household members would have to travel more than 2 km to get arsenic-free water, and this sometimes brought them into conflict with other people. It is worth mentioning that the overall public spending on sanitation, drinking water and health care in Bangladesh is the lowest in the world (WGO, 2012).

4.4. Livelihood strategies

The *char* households have limited scope to diversify their livelihood activities. The irony of this fact is that most of the *char* households are dependent on agriculture. It is reported that a dependence on agriculture-based livelihoods can increase the vulnerability of households which do not diversify (Alam, 2017). Moreover, during the rainy season most of the land in the *char* areas and/or near the river is subject to water logging and flooding which limits their production potential. The households were also found to be cultivating spices, oil seeds and sugarcane in the newly formed *char* lands, which had remained fallow previously due to the unavailability of crop varieties suitable for such land. Therefore, an enabling role should be ensured by both government organizations and NGOs. For example, the government and NGOs can provide the households with livestock support or credit for having livestock since lower income households lack capital. This can serve as an important source of supplementary income.

4.5. Food component

The low resilience capacity of the two groups of households can also be explained by the limited access to food. The situation is worse for the *char* households than for the riverine mainland households (Table 1). The contribution of the food component to reducing the resilience capacity of the *char* households is likely for two reasons: they have to struggle more to manage their food and the local agricultural production is limited to only being able to feed themselves for a few months. Crop cultivation is limited to a very few crops due to the poor soil condition (sandy soils) and land ownership (small farm size mainly due to erosion). The contribution of livestock to food security is also limited. Furthermore, the areas experience more natural disasters than other areas and this results in a loss of livestock and poultry (Alam et al., 2018). During the rainy season, the households used to move their livestock to a safer place, mainly in the nearby embankments or an open place. They would then have to sell their livestock at a lower price and in some cases lose their livestock completely due to sickness. Despite the above factors limiting resilience, households in the *char* area increasingly have adopted resilience activities such as conservation agriculture, homestead gardening, tree plantation, new cropping practices and allowing women to work outside. Similarly, it is encouraging that the households are adopting different livelihood activities such as livestock, poultry and duck rearing, driving, running small businesses such as grocery shops, a tea stall and vendoring that require less capital to be more resilient and at the same time reduce their risk to the impact of the hazards of nature. Many of the households were also found to be using safe drinking water and a sanitary toilet, both of which might be regarded as positive moves to enhance their resilience capacity.

4.6. Social networks and access to institution facilities

The low resilience capacity of the *char* households is also due to the existing low level of social networks. Due to poor socio-economic conditions and inadequate road transport facilities, the households' social network, the key to social capital, was also found to be limited. Research indicates that social capital can greatly enhance vulnerable

households' resilience (Alam et al., 2016; Jordan, 2015; Islam et al., 2014). Households which have strong risk-sharing informal networks have proved to be more resilient to idiosyncratic shocks since risks can be transferred across members and time (Tompkins and Adger, 2004). Such informal networks typically include women's groups, religious groups and cooperative farming groups which are currently lacking in the study area. The *char* households have relatively less access to farmer-to-farmer and government extension service providers from whom they can get advice related to agriculture and livelihood development.

Households in the *char* areas have inadequate access to financial institutions. There exist few government or formal financial institutions, including NGOs, to provide assistance. Such a lack of access can limit the potential to enhance resilience of the underprivileged in a range of ways (Islam and Walkerden, 2015; Barua et al., 2014). For example, it can limit their ability to obtain the resources and technologies they might need for adaptation. After any disaster, households need financial capital to meet their basic needs. Since the *char* households have limited access to familial and kinship networks to gain capital during hazardous events, they are forced to borrow money from informal money lenders who invariably charge high interest rates (Table 1). To repay the loan, sometimes the households need to sell economic assets such as their livestock which otherwise can provide income support and food. This ultimately contributes to reducing the resilience capacity of the household. Moreover, in Bangladesh there are several social safety net programs in operation (e.g., food for work and vulnerable group feeding), but *char* households have less access to these programs mainly due to their lack of transport facilities. Social safety net programs have been criticized for not prioritizing activities to help the most vulnerable people in Bangladesh (Alam, 2016; Alam et al., 2017a,b).

In contrast, the households in the riverine mainland area have a relatively higher education level, more opportunities to diversify their livelihood strategies, better access to food, health and safer water, and are quick to adopt new agricultural practices due to their ready access to agricultural extension services. They have better access to financial institutions owing to the existence and proximity of such service providers, have better use of information and communications technology for various purposes, and have relatively strong social networks. Altogether these factors allow them to show a somewhat more resilient capacity than the *char* households. However, it is important to mention that all riverine mainland households have experienced loss of some of their land and other natural resources. That reduces their production potential and employment opportunities in farming, with a consequent increase in their vulnerability to food insecurity. They were able to supply food from their own production to feed family members for a few months. They experienced more food insecurity during the months of Ashar to Agrahyon (mid-June to mid-November). These months include the rainy seasons in Bangladesh when opportunities for both farming and non-farming activities are reduced significantly. Due to the loss of many market places and the inadequate road and transport facilities because of the erosion hazards, households are required to travel to distant places to sell their products. Moreover, traders were not able to go to the local markets, which reduced the mainland households' chances of obtaining the best prices for their products.

5. Policy implications

This paper has a number of policy implications. For instance, mainstreaming climate change adaptation into development thinking and practices is regarded as a pre-condition for successful interventions. The interventions, in turn, need to be part of a broader climate policy framework, and be targeted to promote a household's capacity development in the area of human capital, social capital and organizational capacity that are likely to contribute to enhancing the resilience of the disadvantaged households. For example, females could be engaged in other income-generating activities such as tailoring, handicrafts or embroidery but these should be facilitated by proper training. Planned adaptation strategies such as access to institutional support and credit facilities might help local communities to cope with the challenges climate change poses to them. The development of high-value crop varieties and adopting technologies suitable to local conditions, especially in the emerging *char* lands, are also important elements in accelerating the process of adaptation. When the crop production environment in erosion-affected areas is somewhat unfavorable, livestock rearing should be encouraged as a policy to enhance resilience capacity. For instance, government organizations and NGOs can provide households with technical support and credit finance for developing livestock when lower economic households face financial constraints. Providing poorly resourced rural households with better information on production techniques, agronomic and land management practices, and climate change issues is also important for accelerating the adoption of adaptation strategies. This will contribute to improved food security and the livelihoods of riverine mainland and *char* households across Bangladesh. Moreover, in the long term, developing the communication and transport networks and infrastructure are also vitally important in order to support alternative livelihoods of the households and to improve their access to markets and available services.

6. Conclusions

This study enhances our understanding of the socio-economic factors affecting the resilience capacity of the most vulnerable riparian rural households in Bangladesh through developing an indicator based index. Such information can assist in better planning of resources, more appropriate allocating of finances, and earmarking resilience-building projects and programs aimed at particular vulnerable rural areas. Although the *char* households display relatively low/less resilience capacity (due to lack or access to food, water and/or access to health services, a limited scope to diversify income, a lack of appropriate adaptation options, or combination of interconnected factors) than riverine mainland households, both have a low RCI value indicating their inability to demonstrate resilience. In other words, this underpins the need for strong intervention by and support from the national government and NGOs so that households can cope with and adapt to climate change and the hazards associated with this phenomenon. This study identifies that access to food, water and health facilities, livelihood strategies and the level of education have contributed to limiting the resilience capacity of households. The strategies for improving access to food, water and health facilities will contribute to a reduction in sensitivity whereas strengthening social-demographic conditions, diversifying livelihood activities and improving access to social networks will enhance the adaptive capacity of the households.

Indicators which by nature provide an 'average' measure of phenomena are tools to simplify the telling of a complex story. The main challenge is to develop robust and sound indicators and to provide scores for the assessment. This is due to the multidimensional nature and complexity of the concept of resilience which varies from area to area and place to place. This study attempts to overcome this issue through adopting a systematic approach to the selection of indicators. In this research the focus has been on quantifying the strength of the current livelihoods and the characteristics of the food and water resources and health facilities as well as the capacity of the households and local communities to alter these strategies in response to climate-related exposures.

The livelihoods of the riparian households are likely to worsen given climate change and the predictions of sea level rises in the future. Therefore, more targeted policies and approaches are required to sustain the livelihoods of hazard-prone rural households across Bangladesh.

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Appendix A. Components and indicators comprising the Resilience Capacity Index (RCI) developed for the study areas (HHs = Households)

Components	Indicators	Score/Values	Possible limitations/ Comments	Source/ Justification of indicators
Socio-demo-graphic profile	Dependency ratio?	If 1:3 score = 1 if > 1.3 = 0	Higher dependency will reduce the resilience capacity. One earning member can lead a family of 3 members properly. It was considered standard with consultation with various people in the area.	Hahn et al. (2009)
	Education level?	Illiterate = 0 Level 1–5 = 1 5–10 = 2 10–12 = 3 > 12 = 4	Education level of household head can increase family income and enhance resilience capacity.	Qasim et al. (2016)
	Do you adopt any contraceptive method?	Yes = 1 No = 0	If no, it means chances of an increase in family size which can reduce the capacity to cope with any shocks.	Alam (2017); Aryal et al. (2014)
	Does your family send children to school?	Yes = 1 No = 0	Some household heads engage their children in some income earning activities due to family need. However, it ultimately reduces his/her future scope to enter into the informal job market and thus more income.	Aryal et al. (2014)
Health issues	Does your family use a sanitary toilet?	Yes = 1 No = 0	This is related to good health as well as being an environmental issue. In the study areas, the households heads physical health condition has influence in terms of access to farm and non-farm activities.	Pandey and Jha (2012)
	Do you have any family members with chronic illness?	Yes = 1 No = 0	Household heads with chronic disease will increase the vulnerability.	Shah et al. (2013); Pandey and Jha (2012)
	Access to health facilities?	Yes = 1 No = 0	Access to health services can contribute to remaining fit and healthy and thus enhance resilience capacity.	Barua et al. (2014); Hahn et al. (2009)
	Current health condition of the household head?	Good = 2 Poor = 1 Sick = 0	Good health is important for doing farm and non-farm jobs. If the household head possesses an underprivileged or sick category of health, it may mean he/she might not get employment and thus become less resilient.	Alam (2016)
Water	Does your family use a tube-well water?	Yes = 1 No = 0	Unsafe drinking water is a source of many diseases that will reduce resilience capacity.	Tambo (2016); Pandey and Jha (2012)
	Distance to the source of safe drinking water?	< 5 minutes' walk = 1 > 5 minutes = 0	A greater distance from a safe drinking water source will increase vulnerability. Household heads agreed that they would walk up to 5 minutes to collect safe drinking water.	Islam et al. (2014); Barua et al. (2014)

Food	Household food secure or not?	Yes = 1 No = 0	Current food security status can reduce vulnerability.	Alam et al. (2017a,b); Tambo (2016)
	Do you adopt zero-tillage cultivation?	Yes = 1 No = 0	Such improved agricultural practices can reduce the production cost particularly for *char* land.	Alam (2016); Islam (2006)
	Do you adopt new cropping practice?	Yes = 1 No = 0	This practice can increase overall food production and enhance household heads' resilience capacity.	Alam (2016)
	Do you adopt improved management of weeds?	Yes = 1 No = 0	This is important for the poor farmers in the face of increasing prices of chemical fertilizers. This practice can enhance household heads' resilience capacity.	Alam (2016)
	Do you adopt improved management of manure?	Yes = 1 No = 0	This practice can increase the agricultural production and improve household heads' resilience capacity.	Alam (2016)
	Do you adopt IPM?	Yes = 1 No = 0	This practice can increase the agricultural production and improve household heads' resilience capacity.	Alam (2016); Islam (2006)
	Do you cultivate multiple crops?	Yes = 1 No = 0	Scope and practices of cultivating multiple crops will improve resilience.	Alam (2016), Aryal et al. (2014)
	How many months can you provide food from your family farm?	No. of months	Households' ability to supply food from their own produce will reduce vulnerability and enhance resilience.	Alam et al. (2017a,b); Aryal et al. (2014)
	Do you practice homestead gardening?	Yes = 1 No = 0	Homestead gardening can contribute to increase household food supply and income earnings.	Alam (2016)
	Do any member of your family included in social safety net programs?	Yes = 1 No = 0	Inclusion in social safety net programs will reduce vulnerability to food insecurity and enhance resilience.	Alam (2016)
Livelihood strategies	What is your main profession?	Agri = 1 Agril + Livestock = 2 Agri + Petty business = 3 Service = 4	Dependence on agriculture increases vulnerability and reduces resilience since agriculture is most vulnerable to climate change.	Alam (2017), Aryal et al. (2014)
	Do you receive remittance from a family member who has migrated to the city?	Yes = 1 No = 0	Remittance can help improve income and thus resilience.	Aryal et al. (2014)
	Do you practice tree plantation?	Yes = 1 No = 0	Tree planting can contribute to an increase in family income and reduce erosion.	Alam et al. (2017a,b)
	Do you allow family women members to work outside home?	Yes = 1 No = 0	Women members having working opportunities outside of the home can contribute to an increase in household income and enhance resilience.	Alam (2016); Aryal et al. (2014)

Social network	Are you a member of a cooperative society?	Yes = 1 No = 0	Involvement in social organizations can reduce vulnerability and improve resilience.	Pandey and Jha (2012); Hahn et al. (2009)
	Have you any savings accounts?	Yes = 1 No = 0	In the face of any disaster household heads are able to rely on this.	Qasim et al. (2016); Aryal et al. (2014)
	Have you received any training in your profession?	Yes = 1 No = 0	It enables HHS to better manage farming activities and increase production/ income.	Alam (2016)
	Do you explore and utilize information technology for professional, health and family planning activities?	Yes = 1 No = 0	Access to and use of information technology can contribute to the reduction of the overall vulnerability and improve resilience.	Alam (2016)
	Are your family members a member of a cooperative society?	Yes = 1 No = 0	It can increase the potentiality of getting assistance and help in case of necessity.	Aryal et al. (2014); Pandey and Jha (2012)
	Do you allow women in the decision-making process?	Yes = 1 No = 0	This is important for effective resource planning within households. It can contribute to enhancing resilience.	Hahn et al. (2009)
	Do you get cooperation from other village people in case of your need?	Yes = 1 No = 0	Normally, lower economic households get less help from others. More sources of support can reduce vulnerability and enhance resilience.	Alam (2017), Aryal et al. (2014)

Note: The provided scores on different indicators were agreed by the household heads of this study during the FGDs.

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